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Land Cover Change in Saipan, CNMI from 1978 to 2009

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Abstract

This paper focuses on the derivation of land cover information from satellite images, and the determination of land cover change in Saipan, the Commonwealth of the Northern Mariana Islands (CNMI), USA. Landsat Multispectral Scanner (MSS) images of October 17, and December 10 of 1978, and two scenes of Aster L1B imagery of March 5, 2009 are employed. This paper concentrates on moderate spatial resolution data for land cover classification and land cover change detection. Higher spatial resolution data including QuickBird, GeoEye, IKONOS data, and historical aerial photos can be employed as reference data. Geospatial technologies such as GIS, spatial analysis and remote sensing are applied to achieve the findings discussed in this paper. Based on the results, Saipan was mostly covered by forest and grassland in both years of 1978 and 2009. Developed areas increased more than 10% from 1978 to 2009, and most of the changes came from forest and grassland. The results may be applied to evaluate impacts of land cover change on water quality, ecosystems and watershed management in Saipan.

Keywords

Land Cover Change; Satellite Images; Remote Sensing; GIS; Saipan

Introduction

Land cover change is not only affected by anthropogenic activities, but also by biophysical drivers and natural driving factors such as droughts, floods, earthquakes, climate change and sea level rise (Lo and Yang, 2002). Examples of Land cover change (LCC) include, but not limited to land clearance for development, change of forests into farming land and human settlement, fires that clear the lands, badland dynamics, and changes in wetlands. These changes can result in soil erosion, which is the main source of non-point pollution for the streams. With the advancement and development of geospatial technologies, it is possible to monitor land cover change and determine the impact of human induced activities on environment and ecosystem in islands, particularly tropical islands where the quantity and quality of water is essential to sustainable development and quality of life. Satellite remote sensing, spatial statistics, geographic information systems (GIS), and global positioning system (GPS) can be employed to identify land cover information and determine land cover changes if temporal data are applied (Jensen, 2000 and 2005; Yuan et al, 2005; Hartemink, Veldkamp and Bai, 2008; Wen and Chambers, 2014). Considering global warming, sea level rise and human induced activities, many island nations or regions are facing serious problems with environmental sustainability, water quantity and water quality, and loss of low-lying lands caused by sea level rise. In order to mitigate the impact of biophysical, climatic and human factors on environment, it is important to obtain land cover information, determine land cover change, and evaluate whether human induced activities affect environment, water quantity and/or water quality.

The Research Advisory Meetings coordinated by the University of Guam Water and Environmental Research Institute and held in Saipan, CNMI identified the following as some of the highest priority research needs for the Commonwealth of the Northern Mariana Islands (CNMI): a). Impact of historical and recent land use activities on ground and surface water quality and production; b). Streamline all agency natural resource data collections into a central repository; c). To develop GIS database for soil erosion and watershed management in the CNMI; and d). To develop an updated watershed atlas for CNMI. The information of land cover and land cover change is crucial to the above mentioned research needs for CNMI. This research focuses on the derivation of land cover

information of Saipan, CNMI from satellite images from Landsat Multi-Spectral Scanner (MSS) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) platforms, and the determination of land cover change in Saipan from 1978 to 2009.

Methodology

Study Area

The study area for this research is the island of Saipan, the Commonwealth of the Northern Mariana Islands (CNMI). Saipan is the second largest island in the Mariana Islands archipelago, after Guam. It is located in about 120 miles north of Guam. Saipan is about 12 miles long and 5.5 miles wide, with a land area of 44.6 square miles. The western coast of the island is mainly composed of sandy beaches and a large lagoon is located in the west. The eastern shore primarily consists of rocky cliffs. Saipan is close to major cities in Asia such as Manila, Hong Kong, Shanghai, Beijing, Seoul and Tokyo. Mount Tapochau at 1.555 feet is the highest on the island of Saipan. Beautiful panoramic views of Saipan can be achieved at Mount Tapochau. The location of Saipan is shown in Figure 1 compared with neighboring countries.

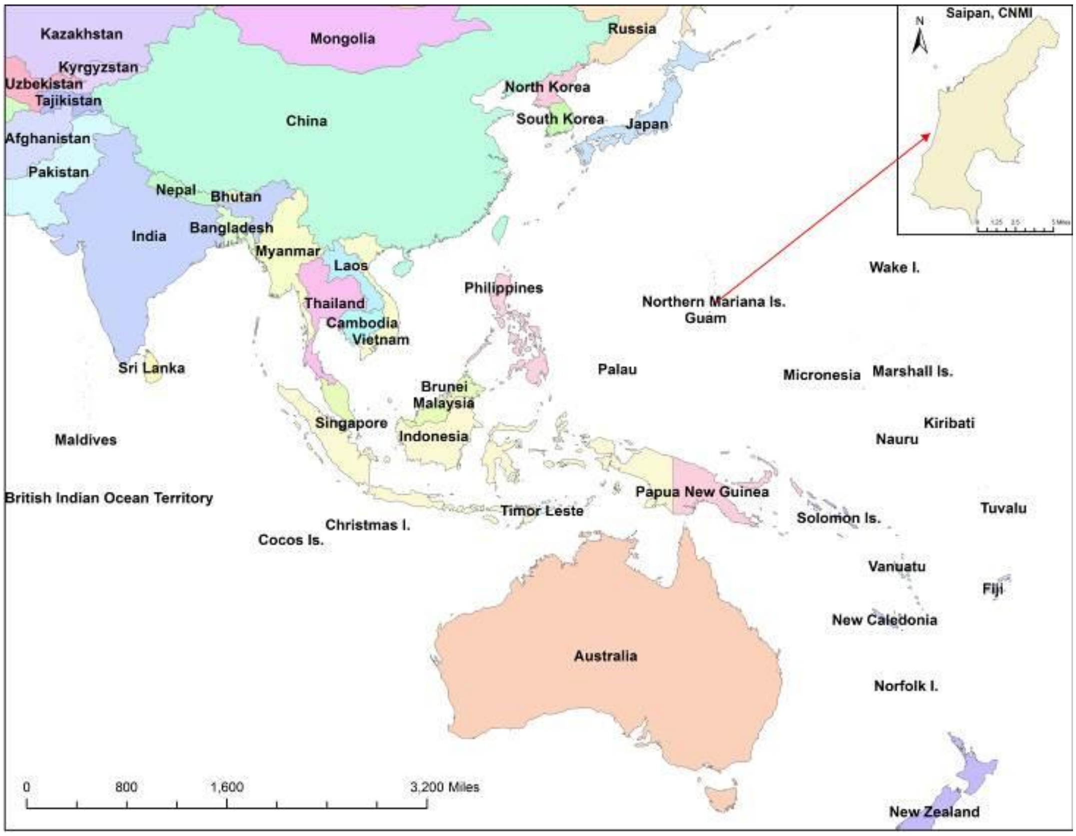

FIGURE 1 LOCATION OF SAIPAN, CNMI

Data Sources and Data Pre-processing

Landsat Multi-Spectral Scanner (MSS) imagery of 1978 and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) L1B imagery of 2009 are available to the research. There are two scenes of Landsat MSS images for 1978, i.e, one of the images was acquired on October 17, 1978, and the other was acquired on December 10, 1978. Both of the images covered the island of Saipan. There are two scenes of ASTER imagers available, both of which were acquired on March 5, 2009. Only one of these ASTER images was not enough to cover the whole island of Saipan. Therefore, both of the images were applied.

The data quality of ASTER L1B imagery of 2009 was very good. However, both of these two scenes of ASTER images were needed to be mosaicked to cover the island of Saipan. One image only covered a small part of Saipan in the north (Figure 2, left), and another one covered most parts of Saipan, but missing a small part of the north

(Figure 2, middle). ERDAS Imagine was utilized to mosaic the ASTER images of 2009. The mosaicked ASTER image could be applied to cover the whole island of Saipan (Figure 2, right).

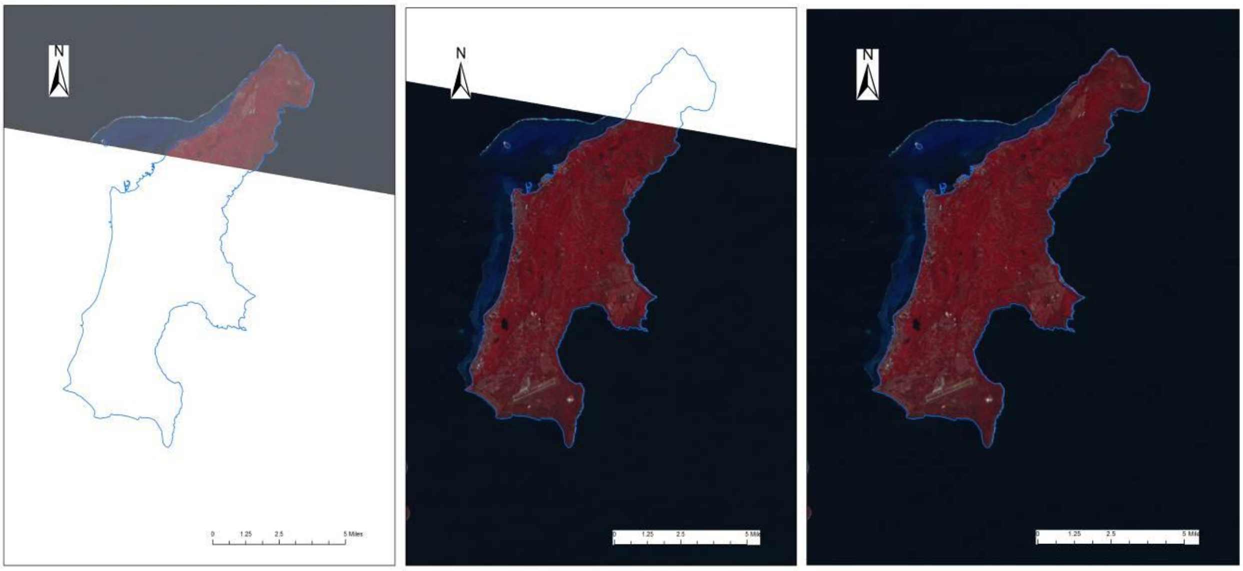

FIGURE 2 ASTER IMAGES OF MARCH 5, 2009

The Landsat MSS satellite imagery of October 17 and December 10 of 1978, shown in the left and right of Figure 3 respectively, had problems with data quality since they were not located in the correct positions, and were covered by a lot of clouds and shadows. The boundary of Saipan is shown in blue, and obviously both of the Landsat MSS images of 1978 are displaced from Saipan. The Landsat image of December 10, 1978 got more problems. Some parts of the Landsat imagery of December 10, 1978 were displaced from their correct locations (Figure 3, right).

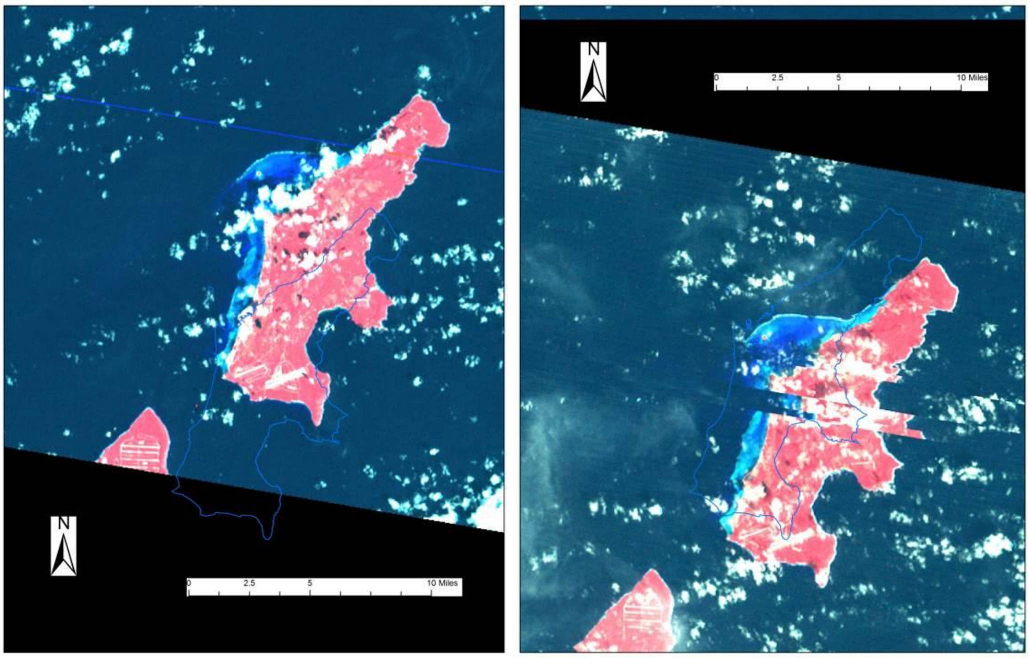

FIGURE 3 LANDSAT MSS IMAGES OF 1978

In order to make the Landsat images of 1978 useful, the images were georeferenced, the displaced parts of Landsat image of December 10, 1978 were adjusted, and clouds and shadows of the images needed to be removed to produce an image of better quality with as few clouds and shadows as possible.

First, both of the images were georeferenced using ArcGIS Georeferencing tool. The mosaicked ASTER image of 2009 was used as reference data for georeferencing. The georeferenced Landsat MSS images of October 17 and December 10 were shown in the left and right of Figures 4, respectively.

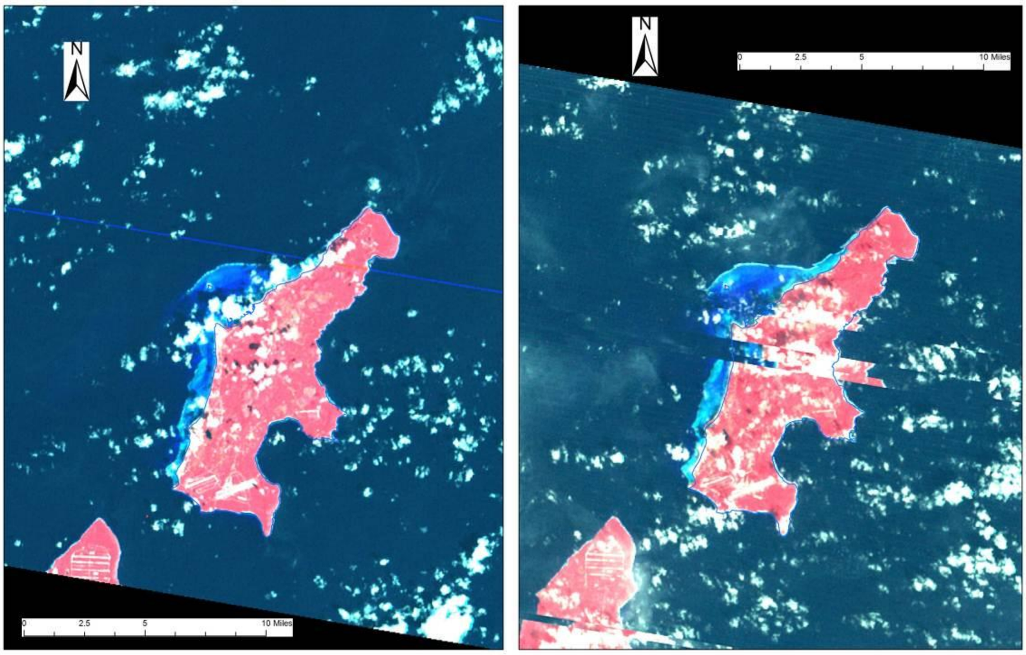

FIGURE 4 GEOREFERENCED MSS IMAGE OF 1978

Secondly, the displaced parts of Landsat image of December 10, 1978 needed to be resolved. The original Landsat MSS images of 1978 covered the whole island of Saipan and a much larger surrounding features including the Pacific Ocean, the Philippine Sea and Tinian in the south of Saipan. Since the studied area was only focused on Saipan, it was necessary to subset the images to a smaller area to cover Saipan. However, considering some parts of the Landsat MSS image of December 10, 1978 displaced from the correct locations, a subset area greater than the study area was applied. ERDAS Imagine was employed to subset the Landsat image of December 10, 1978. ArcGIS Desktop was used to locate the displaced parts, and ERDAS Imagine was used to extract the displaced parts from the original imagery of December 10, 1978, and then ArcGIS Desktop was applied to adjust the displaced parts to correct locations. The adjusted parts were applied to update the original imagery of December 10, 1978 (Figure 5).

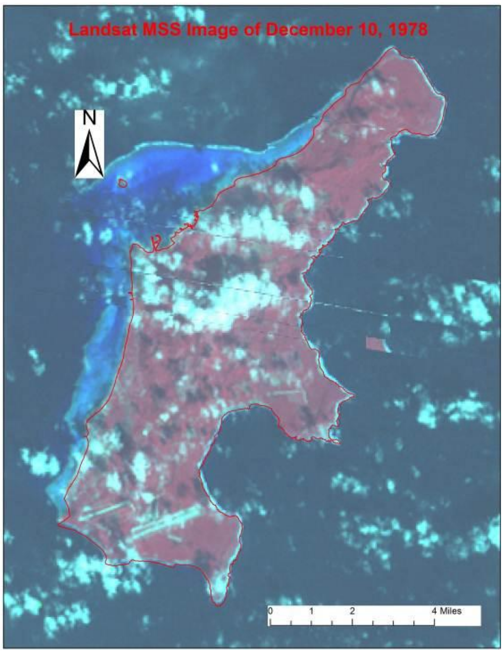

FIGURE 5 GEOREFERENCED IMAGE OFDECEMBER 10, 1978 WITH DOSPLACED PARTS CORRECTED

Next, in order to improve the quality of the Landsat MSS imagery of 1978 and therefore increase the accuracy of land cover classification of the Landsat MSS imagery of 1978, both of the images of October 17 and December 10 of 1978 were used to remove some clouds and shadows.

Since the original satellite images used in the project covered a much bigger area, in order to process the data more efficiently, the boundary of study area was used to subset the imagery for the purpose of land cover change detection in Saipan. ESRI ArcGIS Desktop was applied to buffer the study area for a bigger area to subset the satellite images so that the land cover classification accuracy along shoreline could be improved. Image subsetting was completed in ERDAS Imagine. The subset images for Landsat MSS images of October 17 and December 10, 1978, and ASTER image of 2009 are shown in the left, middle and right of Figure 6, respectively.

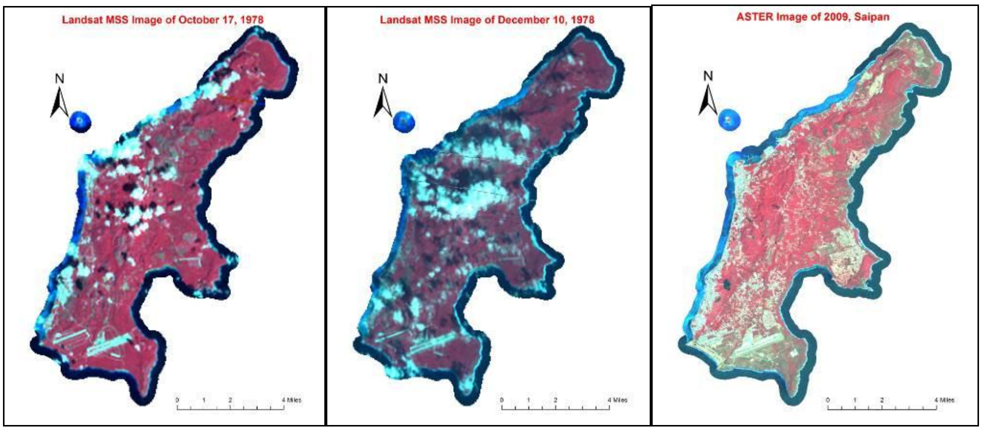

FIGURE 6 SUBSET SATELLITE IMAGES FOR SAIPAN

The subset images of 1978 in Figure 6 indicated that there were lots of clouds and shadows in the Landsat MSS images of 1978. In order to improve the accuracy of the land cover information derived from the Landsat MSS images, it was necessary to remove as many clouds and shadows as possible from the images. Since it was very difficult to differentiate between water and shadows, water was also removed at the beginning. The Landsat MSS images of 1978 indicated that the data quality of Landsat MSS image of October 17, 1978 was better than that of Landsat MSS image of December 10, 1978 because there were much more coverages of clouds and shadows in the latter image. The coverages of clouds, shadow and water from Landsat images of October 17, and December 10, 1978 were created. Such information was applied to remove clouds and shadows from Landsat MSS images of 1978. The final Landsat MSS image of 1978 was a fused data from both of the images of 1978 with much fewer clouds and shadows (Figure 7). More details about how clouds and shadows were removed are discussed in Wen and Chambers, 2014. So far, the Landsat MSS image of 1978 processed from Landsat MSS images of October 17 and December 10, 1978 with clouds and shadows removed and the mosaicked ASTER image of 2009 could be applied to extract land cover information.

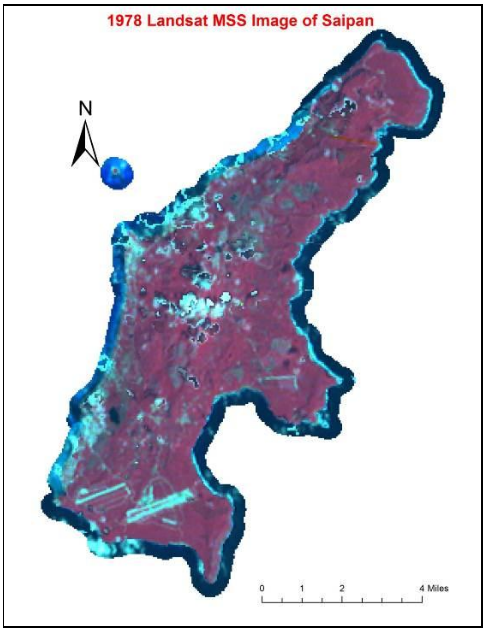

FIGURE 7 LANDSAT MSS IMAGE OF 1978

Methods

The GIS, remote sensing, and spatial analysis were used to extract land cover information from satellite images, and determine land cover changes. The GIS Lab at the Water and Environmental Research Institute (WERI), University of Guam, USA is equipped with the state of the art workstations, a big size plotter, ERDAS Imagine and ArcGIS Desktop Advanced with extensions such as Spatial Analyst and Geostatistical Analyst. ArcGIS Desktop and ERDAS Imagine were the main tools used to process satellite images, and both of the softwares were applied to conduct land cover classification. When land cover information was derived from Landsat MSS image of 1978 and ASTER image of 2009, land cover change could be determined, and change patterns could be evaluated.

In order to determine land cover change in Saipan, two scenes of Landsat MSS images from different dates, i.e., October 17, 1978 and December 10, 1978 were applied to derive land cover information of 1978. Processing of the Landsat MSS images of 1978 was discussed in details in the previous section, including Data Sources and Data Processing. Two scenes of ASTER satellite images of March 5, 2009 were obtained to extract land cover information of 2009. Integration of remote sensing, GIS and spatial analysis was the primary method applied to obtain land cover information from the satellite images of Landsat MSS and ASTER in the project. ArcGIS Desktop, particularly map algebra, was utilized to measure the land cover changes in Saipan.

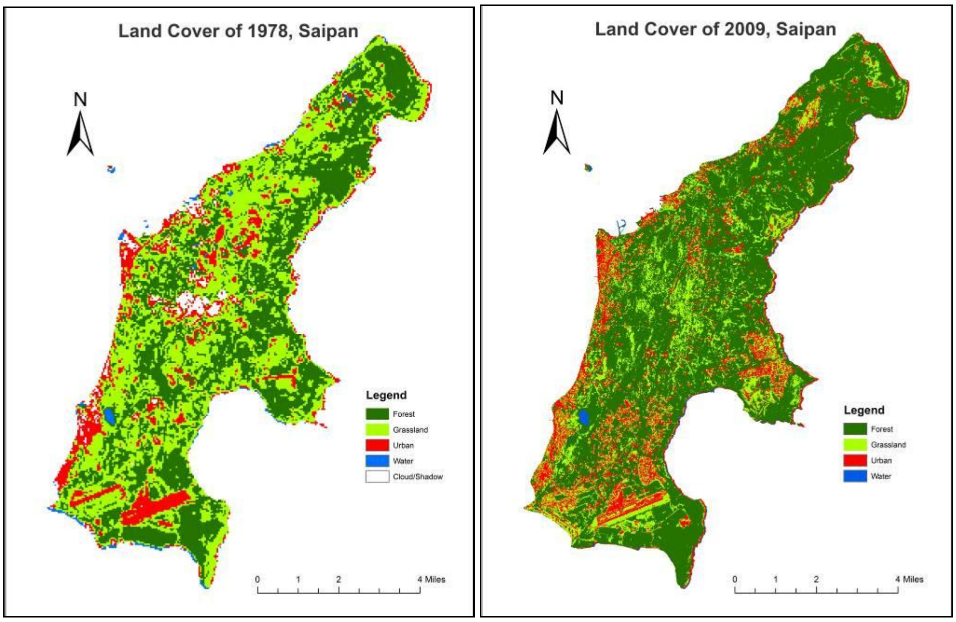

FIGURE 8 LAND COVER MAPS OF 1978 AND 2009

For this research, unsupervised and supervised classification methods were applied to derive land cover information for the available satellite images. It was very time-consuming and difficult to extract land cover information from the Landsat MSS image of 1978 because of relatively low data quality, and coarse spatial resolution. Five general land cover classes, i.e., urban area, forest, water, grassland and cloud were applied. Unsupervised classification method in ERDAS Imagine was employed to generate classes based on features on the Landsat MSS image. Based on the results from unsupervised classification, five general land cover classes were generated based on supervised classification with the basis of the patterns, shapes, textures, tones and colors from the mosaicked Landsat MSS image of 1978. However, there were some errors found from the land cover information obtained from unsupervised and supervised classifications. The airstrip located in Kagman was missing. On-screen digitization in ArcGIS Desktop was used to delineate the airstrip in Kagman. Some parts of Saipan International Airport were misclassified. A subset image was created to cover the area of Saipan International Airport, and developed area in the airport was extracted based on a supervised classification of an unsupervised classification result. Then, a further supervised classification was conducted to correct some misclassified classed from the results of unsupervised classification of Landsat MSS image of 1978. Since the land cover information was focused on the buffered study area, the boundary of the study area needed to be used to clip the classified land cover to the extent of the study area. The final land cover information of 1978 is shown in Figure 8, left.

The data quality of ASTER image of 2009 was very good. Four general land cover categories including forest, urban area, grassland and water were used to extract land cover information from ASTER image of 2009. Unsupervised classification method in ERDAS Imagine was used to derive land cover information from ASTER image of 2009. Then, supervised classification was utilized to obtain four general land cover categories of forest, urban area, grassland and water based on patterns, shapes, tones and textures of the image. The final step to achieve the land cover information of 2009 in Saipan was to clip the land cover information using the boundary of the study area (Figure 8, right).

Conclusions and Discussions

Landsat MSS images of October 17, 1978 and December 10, 1978 were used to derive land cover information of 1978 for Saipan. Two ASTER images of March 5, 2009 were applied to cover the whole island of Saipan, and employed to extract land cover information of 2009 for Saipan. The Landsat MSS images of 1978, especially the Landsat MSS image of December 10, 1978, were covered by a lot of clouds and shadows. Furthermore, there were some displaced areas in the Landsat image of December 10, 1978. These Landsat images were also not aligned with the study area. Therefore, efforts needed to be invested to georeference the Landsat images, remove clouds and shadows, and resolve the displaced parts from the Landsat image of December 10, 1978. The ASTER image of 2009 did not have any quality problems. However, they needed to be mosaicked to cover the island of Saipan.

The land cover information of 1978 for Saipan was derived from the Landsat MSS imagery of October 17 and December 10 of 1978. The land cover information of 2009 was derived from the ASTER L1B imagery of March 5 of 2009. Land cover maps of 1978 and 2009 in Saipan are listed in Figure 8 side by side for visual comparison. By comparison of the land cover data between 1978 and 2009, the following conclusions can be made (Tables 1 and 2). Saipan was mainly covered by forest and grassland both in 1978 and 2009. The area of forest increased by about 2,923.4 hectares, or 60.88% from 1978 to 2009, and the area of grassland decreased by about 2,672.64 hectares or about 52.1% between 1978 and 2009. The built-up/urban area increased by about 165.6 hectares or 11.6% from 1978 to 2009, and most of the increased urban areas occurred in forest and grassland.

TABLE 1 OVERALL LAND COVER CHANGE (UNIT: HECTARE)

1978 \ 2009	Forest	Grassland	Urban	Water	Total
Forest	3,584.88	844.92	390.60	7.56	4,827.96
Grassland	3,412.80	1,051.92	648.36	14.04	5,127.12
Urban	554.40	423.00	433.82	13.68	1,424.88
Water	52.20	20.16	25.92	25.20	123.48
Cloud	163.08	114.48	91.80	8.64	378.00
Total	7,767.36	2,454.48	1,590.48	69.12	11,881.44

TABLE 2 OVERALL LAND COVER PERCENTAGE CHANGE (%)

1978 \ 2009	Forest	Grassland	Urban	Water	Total
Forest	74.25	17.50	8.09	0.16	40.63
Grassland	66.56	20.52	12.65	0.27	43.15
Urban	38.91	29.69	30.44	0.96	11.99
Water	42.27	16.33	20.99	20.41	1.04
Cloud	43.14	30.29	24.29	2.29	3.18
Total	65.37	20.66	13.39	0.58	100.00

Some pictures about the significant features of the Saipan environment were taken by a GPS camera. The geotagged pictures can be used as references to verify land cover information derived from satellite imagery. The land cover information can also be used to evaluate environmental concerns such as soil erosion, water quality and non-point source pollution. It can also be utilized to evaluate whether there is relationship between landscape change and climate change, and how land cover change affects watersheds, water quality and ecosystems in

watersheds of Saipan. The findings and approaches from this research may be utilized to conduct research on land cover change detection in other islands affected by anthropogenic activities, impacts of human induced activities, impacts of climate change and land cover change on environmental and landscape change in such islands.

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